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UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

COAL-MINE ACCIDENTS: THEIR CAUSES AND PREVENTION

A PRELIMINARY STATISTICAL REPORT

BY

CLARENCE HALL AND WALTER O. SNELLING

WITH INTRODUCTION BY

JOSEPH A. HOLMES

IN CHARGE OF TECHNOLOGIC BRANCH

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INTRODUCTION.

By Joseph A. Holmes.

The general supervision of the work of the coal-mine inspectors in New Mexico and Indian Territory was transferred on June 10, 1907, by the Secretary of the Interior to the Geological Survey in a letter from which the following paragraphs are extracted:

> I have to request that from and including the 1st day of July, 1907, you will take up the practical administration of the act for the protection of the lives of miners in the Territories, approved March 3, 1891, and the act amendatory thereof, approved July 1, 1902, and the supervision of the work of the coal-mine inspectors in New Mexico and the Indian Territory appointed pursuant to said statute, and those who may hereafter be appointed in such Territories in which the aggregate annual output is in excess of 1,000 tons of coal.
>
> In this connection it is suggested that the officers of the Geological Survey having the matter in charge should not only investigate the general mining conditions in the Territories, but also the nature and extent of the mine accidents, particularly those resulting from explosions, and report to the Department the results of such investigations. These reports should contain also suggestions as to how the mining conditions may be improved and accidents prevented, without undue hardship to the operators.

In a letter dated June 14, 1907, this supervision of the work of the coal-mine inspectors was placed by the Director of the Survey under the technologic branch of that organization. In endeavoring to carry out the suggestions of the Secretary relative to the improvement of the mining conditions and prevention of mine accidents in the coal mines of the Territories, a number of examinations of the more dangerous coal mines of the Indian Territory were made by Clarence Hall, Samuel Sanford, Rollin T. Chamberlin, and the expert in charge of the technologic branch. Other and more extended examinations of the coal mines of both Indian Territory (Oklahoma) and New Mexico have been planned. Meanwhile Mr. Hall and his associates have been investigating the nature, extent, causes, and results of a number of disastrous coal-mine explosions in several of the States. These studies have been carried on in connection with the general investigation of the waste and destruction of coal in mining operations.

In connection with all these investigations, and with a view to determining the practicability of preventing coal-mine explosions and improving mining conditions, a general inquiry was begun by Mr. Hall, with the assistance of Walter O. Snelling and under the advice of Prof. Charles E. Munroe, concerning the nature and extent of such explosions and the methods employed in the United States or in foreign countries to prevent their occurrence.

In response to numerous requests for information on this subject, a brief summary of the results of these inquiries has been prepared for immediate publication as the present bulletin. Later bulletins will deal with other phases of this subject and also embody the results of the investigations of coal mining and coal-mine accidents in the Territories.

The figures given in this report indicate that during the year 1906 nearly 7,000 men were killed or injured in the coal mines of this country, and that the number of these accidents caused directly or indirectly by mine explosions has been steadily increasing. It is also indicated that this increase has been due in part to the lack of proper and enforceable mine regulations; in part to the lack of reliable information concerning the explosives used in mining, and the conditions under which they can be used safely in the presence of the gas and dust encountered in the mines; and in part to the fact that in the development of coal mining not only is the number of miners increasing, but many areas from which coal is being taken are either deeper or farther from the entrance, where good ventilation is more difficult and the dangerous accumulations of explosive gas more frequent.

The increase both in the number and in the seriousness of mine explosions in the United States during past years may be expected to continue unless, through investigations made in the United States such as have proved effective in other coal-producing countries, information can be obtained and published concerning the explosives used, the conditions under which they may be used safely in the presence of coal dust or gas, and the general conditions which make for health and safety in coal-mining operations. Such information, obtained through comprehensive and impartial investigations, may serve in this, as in other countries, as an intelligent basis both for legislative enactments and for agreements among persons associated with mining operations.

One after another of these terrible underground disasters awakens the sympathies of the nation and arouses an earnest desire that they may be entirely prevented. Experience in the deeper and more dangerous coal mines of Belgium and other countries not only indicates that these mine accidents may be reduced to less than one-third their present number in the United States, but also gives promise of results which in the future may at least approach complete prevention.

COAL-MINE ACCIDENTS: THEIR CAUSES AND PREVENTION—A PRELIMINARY STATISTICAL REPORT.

By Clarence Hall and Walter O. Snelling.

STATISTICS RELATING TO ACCIDENTS IN COAL MINES.

FATAL ACCIDENTS IN THE UNITED STATES.

In the coal mines of the United States in 1906, 6,861 men were killed or injured, the number killed being 2,061 and the number injured being 4,800.

The number of men killed in the coal mines of the United States for each year from 1890 is shown in the following table:

Number of men killed in the coal mines of the United States, 1890–1906.

1890	701	1900	1,493
1891	1,076	1901	1,594
1892	859	1902	1,828
1893	965	1903	1,794
1894	957	1904	1,999
1895	1,057	1905	2,097
1896	1,120	1906	2,061
1897	947	Total	22,840
1898	1,049		
1899	1,243		

The total number of men killed since 1889, as shown above, is 22,840. It will be noted that as many violent deaths have occurred in the coal mines of the United States during the last six years as during the preceding eleven years, the number of fatal accidents having practically doubled within that time.

NUMBER OF MEN KILLED FOR EACH THOUSAND EMPLOYED.

INCREASE IN THE UNITED STATES.

The great increase in the production of coal during the last decade, and the related increase in the number of men employed in the industry, may seem to account for the increase in the number of fatal accidents. But the following table, giving the number of men killed for each 1,000 employed, shows that the increase can not be accounted for in this way:

Number of men killed in the coal mines of the United States for each 1,000 men employed.

1895	2.67
1896	2.79
1897	2.34
1898	2.59
1899	2.98
1900	3.24
1901	3.24
1902	3.49
1903	3.14
1904	3.38
1905	3.53
1906	3.40

DECREASE IN EUROPEAN COUNTRIES.

PROTECTIVE LEGISLATION.

In all the European coal-producing countries the output of coal has increased greatly during the last ten years, but the number of deaths per 1,000 miners, instead of increasing as in this country, has undergone a marked and decided decrease. This decrease has been due to the effect of mining legislation in those countries for the safeguarding and protection of the lives of the workmen, and has been made possible by government action in establishing testing stations for the study of problems relative to safety in mining, including the use of explosives.

BELGIUM.

The decrease in Belgium is shown in the following table:

Number of men killed for each 1,000 men employed in the coal mines of Belgium for each decade since 1830.

1831–1840	3.19
1841–1850	3.18
1851–1860	3.28
1861–1870	2.60
1871–1880	2.36
1881–1890	1.99
1891–1900	1.39
1901–1906	1.02

It will be seen from the above table that the study of mining conditions in Belgium has resulted in a reduction of the death rate per 1,000 men employed to one-third of the ratio now existing in the United States. It seems certain that if a similar study of mining conditions were to be made in the United States and proper legislation could be secured to enforce the conditions found to be necessary for a better safeguarding of the lives of the miners, the death rate from mine accidents would be greatly reduced. The following table gives the death rate from accidents in the coal mines of Belgium in the years 1895–1906:

Number of lives lost in the coal mines of Belgium for each 1,000 men employed.

1895	1.40
1896	1.16
1897	1.03
1898	1.04
1899	.97
1900	1.05
1901	1.16
1902	1.07
1903	1.14
1904	.93
1905	.91
1906	.94

GREAT BRITAIN.

The number of men killed in the coal mines of Great Britain for each 1,000 men employed is shown for each year since 1890 in the following table:

Number of men killed in the coal mines of Great Britain for each 1,000 men employed.

1891	1.50	1899	1.26
1892	1.49	1900	1.30
1893	1.55	1901	1.36
1894	1.60	1902	1.24
1895	1.49	1903	1.27
1896	1.48	1904	1.24
1897	1.34	1905	1.35
1898	1.28	1906	1.29

PRUSSIA.

The number of men killed in the coal mines of Prussia for each 1,000 men employed is shown for a number of years in the following table:

Number of men killed in the coal mines of Prussia for each 1,000 men employed.

1861-1866	2.66	1897	2.35
1867-1880	2.94	1898	2.86
1881-1890	2.93	1899	2.31
1891	2.89	1900	2.25
1892	2.21	1901	2.34
1893	2.62	1902	1.99
1894	2.21	1903	1.92
1895	2.54	1904	1.80
1896	2.58		

FRANCE.

In France the number of lives lost per 1,000 men employed has been very low for a number of years, but since the publication of the last available report an explosion has occurred at the Courrieres mine in that country, causing the death of more than 1,000 miners, and this would materially affect the result of any tabulation. The number of lives lost per 1,000 men employed for each year for which statistics are available is as follows:

Number of lives lost in the coal mines of France for each 1,000 men employed.

1901	1.03
1902	.95
1903	.86
1904	.89
1905	.84

COMPARATIVE SUMMARY.

On comparing the average death rates from accidents in coal mines for each 1,000 men employed in different countries the full significance of the figures already given may be seen.

In the following table, giving the average ratio for the last period of five years for which statistics are at hand, the position of the United States may be compared with that of the principal European coal-producing countries:

Number of men killed for each 1,000 men employed—averages for five years.

France (1901–1905)	0.91
Belgium (1902–1906)	1.00
Great Britain (1902–1906)	1.28
Prussia (1900–1904)	2.06
United States (1902–1906)	3.39

Belgium maintains the most thoroughly equipped testing station in the world, and for a number of years has carried out extensive experiments to devise means to prevent accidents and to increase the safety of workers in the mines. The success of these experiments will be better realized when it is stated that at the beginning of the investigations the number of men killed each year for each 1,000 men employed was 3.2, or very nearly that now shown for the United States, while at present it is less than one-third of that number.

Great Britain and Germany also maintain testing stations, where every question relating to the testing of explosives, safety lamps, rescue devices, and all similar matters may be submitted to experimental studies. As the result of this foresight great reductions have been made in the number of accidents in the coal mines of those countries.

CAUSES OF MINE ACCIDENTS.

FATAL ACCIDENTS FROM FALLS OF ROOF AND COAL.

In 1906 the causes of the fatal and nonfatal accidents in the coal mines of the United States were as follows:

Coal-mine accidents in the United States, 1906.

Accidents due to—	Killed.	Injured.
Gas and dust explosions	228	307
Powder explosions	80	215
Falls of roof and coal	1,008	1,863
Other causes	732	2,192

It will be noted that 50 per cent of all the fatal accidents and 39 per cent of all the nonfatal accidents were the result of falls of roof and coal, and that accordingly these are the most prolific source of accidents in the coal mines of the United States. The following statement of deaths from this cause per 1,000 men employed shows how the United States compares with several of the foreign coal-producing countries in this regard:

Deaths from falls of roof and coal per 1,000 men employed.

Belgium	0.40
France	.47
Great Britain	.64
Germany	.92
United States	1.70

In all the countries mentioned, except the United States, the use of excessive charges of explosives is prohibited by law, and definite limits are set as to the amount of any explosive that may be used. Although these regulations were framed with the object of preventing gas explosions, it is believed that they have been of marked effect in preventing accidents from falls of roof and coal, as the very great disturbing and jarring effect exerted by the discharge of large amounts of explosives in a mine is believed to be one of the most important causes of falls of roof. The actual fall of the rock or coal may not occur at the time of firing the charge, but the heavy shots weaken the wall and roof and start cracks that impair the support of the rock, so that months after the blast, without warning, the roof or wall falls.

It is also to be noted that explosions of fire damp and coal dust have a similar effect in jarring and weakening the walls and roof, and in gassy regions, where small explosions of fire damp are of frequent occurrence, falls from this cause may make up a considerable percentage of the total number. But even in such regions the use of explosives and unsatisfactory forms of lamps is generally the indirect cause of the fall, for nearly all explosions of fire damp are caused by ignition from the shots used in breaking out the coal or from naked lights used by the miners.

In all foreign countries from which statistics are available restrictions in the maximum amount of explosives allowed to be used have not only increased the safety from explosions of gas, but have also materially diminished the loss of life from falls of roof.

The following table shows the number of deaths per 1,000 men from falls of roof and coal in France for each five-year period since 1870:

Number of men killed from falls of roof and coal in France for each 1,000 men employed.

1871–1875	1.26
1876–1880	.95
1881–1885	.88
1886–1890	.62
1891–1895	.59
1896–1900	.47

The steady decrease in the death rate from this cause is noteworthy, and is undoubtedly due largely to the greater stability of the sides and roof when free from the jarring and fissuring effect of large charges of explosives.

In Belgium, results similar to those obtained in France have followed the reduction of the allowed charges, as will be seen from the following table:

Number of men killed from falls of roof and coal in Belgium for each 1,000 men employed.

1851–1860	0.998
1861–1870	.898
1871–1880	.708
1881–1890	.661
1891–1900	.512
1901–1904	.406

In Great Britain and Germany the results are similar to those in France and Belgium, and thus the evidence on this subject is found to be consistent, and to point uniformly to the conclusions mentioned.

FATAL ACCIDENTS FROM GAS AND DUST EXPLOSIONS.

Gas and dust explosions form another important cause of mine accidents. In the United States during 1906 11 per cent of all the deaths in coal mines were due to such explosions.

In general, explosions of coal dust and fire damp are brought about either by ignition from explosives used in mining or from miners' lamps. Both of these causes have received careful study at the foreign testing stations, and the result of the legislation which has followed is well shown in Belgium, where gas is particularly prevalent in the mines, but where, through precautions resulting from the study of the conditions that favor explosions, loss of life from this cause has been reduced to a minimum. The following statement shows how successful the results in this direction have been:

Number of men killed from explosions of fire damp in Belgium for each 1,000 men employed.

1831–1840	0.965	1871–1880	0.487
1841–1850	.764	1881–1890	.364
1851–1860	.428	1891–1900	.208
1861–1870	.344	1901–1904	.039

From this statement it will be seen that the number of fatal accidents resulting from the explosion of fire damp have been so greatly reduced that the present death rate from this cause is but one-tenth of that of thirty years ago. This has been due to systematic testing of safety lamps, only those forms being allowed to be used which are capable of withstanding rapidly moving currents of fire damp under all conditions likely to be encountered in mines, and to thorough testing of all explosives to determine the amount of each which can be fired without danger of explosions of fire damp or coal dust.

FATAL ACCIDENTS FROM OTHER CAUSES.

Other causes of fatal accidents in coal mines, such as defective hoisting machinery, suffocation by carbon dioxide or poisonous gases, collision of coal cars, and many other causes of similar nature, are generally within the control of the State mine inspectors, and if a sufficient number of intelligent and capable inspectors are provided accidents of this character may be kept within very close limits without great difficulty.

NUMBER OF MEN KILLED FOR EACH MILLION TONS OF COAL PRODUCED.

UNITED STATES.

When the total number of fatal accidents in the coal mines of the United States is considered with reference to the number of tons of coal produced, it is seen that the number of men killed for each million tons of coal produced has not changed materially in the last fifteen years. The following table shows the number of men killed in the coal mines of the United States for each million long tons of coal produced in each year since 1890:

Number of men killed in the coal mines of the United States for each million tons of coal produced, by years.

1890	4.97	1899	5.49
1891	7.14	1900	6.20
1892	5.36	1901	6.08
1893	5.93	1902	6.79
1894	6.28	1903	5.62
1895	6.13	1904	6.24
1896	6.53	1905	5.97
1897	5.30	1906	5.57
1898	5.34		

Considered in periods, the average results obtained are as follows:

Number of men killed in the coal mines of the United States for each million tons of coal produced, by periods.

General average, 1890–1906	5.93
1890–1895	5.97
1896–1900	5.77
1901–1906	6.04

It is very doubtful whether natural conditions in any other country in the world are so favorable as in the United States for getting out coal with the minimum amount of danger to the workmen employed. The structural relationships in the principal coal districts of the United States are entirely favorable, and beds of 4, 5, and 6 feet in thickness, lying in nearly horizontal positions and providing almost ideal conditions for mining, make up a greater proportion of the coal properties in active development than in any other coal-producing country.

The coal mines of the United States, considered as a whole, are not troubled by fire damp to any greater extent than the mines of most other countries. The abundance and cheapness of timber in this country in the past should also have been factors of considerable importance in reducing the number of accidents in mines, inasmuch as with abundant timber the use of sufficient props to support the roof and sides would not be prevented by the factor of cost.

But in spite of all the natural conditions tending to reduce the percentage of mine accidents in the United States to a low figure, the accidents during the last fifteen years show directly contrary results. Considered in regard to the number of deaths per 1,000 men employed, the United States, as has already been pointed out, occupies a less favorable position than any other of the coal-producing countries, more than three times as many men out of each 1,000 employed being killed as in some of the European countries that are much less favored in natural conditions. In regard to deaths per million tons of coal the United States not only occupies a position worse than that of most of the European countries, but is also showing an increase in the rate, whereas every other country is showing a decrease.

EUROPEAN COUNTRIES.

The following statement shows the figures for Great Britain:

Number of men killed in the coal mines of Great Britain for each million tons of coal produced.

1874–1883	7.42
1884–1893	5.65
1894–1903	4.70
1904	4.41
1905	4.64
1906	4.31

For France the figures are as follows:

Number of men killed in the coal mines of France for each million tons of coal produced.

1900	5.55
1901	5.21
1902	4.80
1903	4.20
1904	4.55
1905	4.17

For Belgium, which is troubled with fire damp to a greater extent than any other coal-producing country, the figures are not so good as those just given for France; but even in Belgium better results have been obtained for the three years 1904–1906 than in the United States, as will be seen from the following table:

Number of men killed in the coal mines of Belgium for each million tons of coal produced.

1895	7.70
1896	6.39
1897	5.77
1898	7.78
1899	5.77
1900	5.96
1901	6.93
1902	6.29
1903	6.68
1904	5.66
1905	5.64
1906	4.96

Prussia shows less favorable results than the United States in regard to lives lost per million tons of coal, yet during the last ten years there has been an almost steady decrease in the number killed per million tons mined, and the number of lives lost per 1,000 men employed has also decreased from 2.54 to 1.80, showing that the high death rate based on amount of coal produced is largely due to the natural conditions existing in the coal mines of that country.

CONCLUSIONS.

It has already been stated that in no country in the world are the natural conditions so favorable for the safe extraction of coal as in the United States, and it has also been pointed out that in spite of this fact the number of lives lost per 1,000 men employed is far higher than in any other coal-producing country, and that the number of lives lost per million tons of coal produced is exceeded by only one other country. It now remains to be shown that unless energetic means are taken to counteract this prevailing tendency not only will the death rate in proportion to men employed and tons produced increase as it has done in the last few years, but it will increase at a much more rapid rate.

With the depletion of the thicker and more favorably mined seams of coal, thinner and less regular seams must be worked. This factor will undoubtedly be of the greatest importance within a comparatively few years, and the natural result would be to greatly increase the death rate. The rising price of timber will have the effect of decreasing the number of wooden props used in mining, and probably will increase the chance of accidents from falls of roof and coal. Another important factor in the mines of the United States is to be found in the nationality of the miners. Most of the men are foreign born, a large proportion of them are unable to understand English freely, and a still larger number are unable to read or write that language. Some of them are inexperienced and do not take proper precautions either for their own safety or for the safety of others. This becomes a most serious menace unless they are restrained by carefully enforced regulations.

With the mining of the smaller beds of coal and the gradual development of properties worked with more difficulty, bringing the mining conditions in the United States more nearly to a position of equality with those abroad, a great increase in the number of accidents must be expected unless proper steps are taken to remedy the conditions that have brought about the present remarkably high death rate in the coal mines of the United States.

PREVENTION OF MINE ACCIDENTS.

The successful results which have attended efforts made in European coal-producing countries to reduce the dangers of coal mining have already been mentioned. The most important of the means through which these results have been achieved, in the opinion of the investigators who have had the matter in charge, will now be considered and some of the regulations governing coal-mine operations in foreign countries will be briefly discussed. No mention is made herein of many of the admirable precautions taken in some of the foreign mining districts for combating unfavorable local conditions, and many regulations, such as those in regard to timbering, spacing of pillars, and width of rooms and entries, will be taken up in a later paper.

SAFETY LAMPS.

The compulsory use of safety lamps in mines having a dangerous amount of fire damp is general in all the European coal-producing countries. The regulations on this subject for Great Britain are as follows:[a]

Rule 8. No lamp or light other than a locked safety lamp shall be allowed or used (*a*) in any place in a mine in which there is likely to be any such quantity of inflammable gas as to render the use of naked lights dangerous; or (*b*) in any working place approaching near a place in which there is likely to be an accumulation of inflammable gas.

And when it is necessary to work the coal in any part of a ventilating district with safety lamps, it shall not be allowable to work the coal with naked lights in another part of the same ventilating district, situated between the place where such lamps are being used and the return airway.

Rule 9. Whenever safety lamps are used, they shall be so constructed that they may be safely carried against the air current ordinarily prevailing in that part of the mine in which the lamps are for the time being in use, even though such current should be inflammable.

---

[a] Coal-mines regulation act, 1887, paragraph 49.

The laws of the other coal-producing countries are similar in essential particulars to those of Great Britain.

The keeping of at least two safety lamps in all mines (whether thought to be gaseous or not) is also required in some countries; and laws regulating the manner of locking safety lamps and requiring that all lamps shall be capable of being so locked by magnetic devices, compressed air, or other means, as not to be opened by any unauthorized person, are also in effect.

The employment of relighting stations, at which locked safety lamps may be relighted in the mine when they are accidentally extinguished, is permitted in several countries. In the coal-mines regulation act of Great Britain, rule 10, it is stated that relighting stations must not be in the return air from any part of the mine in which safety lamps are required to be used, the object of this provision being to prevent the possibility of fire damp being ignited at the relighting station and passing back to the workings. In Belgium and Germany the lamps in use are equipped with relighting devices of approved design, and are known to be practically free from danger of igniting fire damp, so that relighting stations are unnecessary.

Provisions regarding the examination of safety lamps at regular intervals by some competent person, to see that they are kept in safe condition, and regulations forbidding the possession by any unauthorized person of any contrivance for opening the lock of any safety lamp are also generally in force in France, Belgium, Germany, and Great Britain.

USE OF EXPLOSIVES.

The various commissions which have been appointed by Great Britain, France, Germany, and Belgium for the study of mining conditions have brought out the fact, thoroughly proved by experiment and by actual tests in mines, that certain types of explosives are much more liable than others to ignite fire damp and thus to cause gas explosions. This is true whether we consider (1) a test based on equal weights of the two explosives or (2) the fairer test of such weights of each as have equally powerful effects.

Accordingly, in all the European coal-producing countries, regulations have been made forbidding the use of such explosives as are known to be most dangerous in this respect, in all mines in which fire damp is liable to be present to a dangerous extent, and requiring the use in these mines of such explosives as have been proved to be reasonably free from the danger of igniting explosive-gas mixtures.

The order regulating the use of explosives in Great Britain contains the following provisions:

(*a*) In all coal mines in which inflammable gas has been found within the previous three months in such quantity as to be indicative of danger no explosive, other than a permitted explosive as hereinafter defined, shall be used in or taken for the purpose of use into the seam or seams in which the gas has been found or any shaft or drift communicating therewith which is in process of being deepened or sunk, or being driven, as the case may be.

(*b*) In all coal mines which are not naturally wet throughout no explosive, other than a permitted explosive as hereinafter defined, shall be used in or taken for the purpose of use into any road or any dry and dusty part of the mine, or any shaft or drift communicating therewith, which is in process of being deepened or sunk, or being driven, as the case may be.

The "permitted explosives" to which reference is made are those explosives which have been found, after testing at the Government experiment station, to be capable of being fired in an explosive-gas mixture without causing the ignition of the gas. A "list of permitted explosives" is kept, including all those explosives that answer the required test, and all explosives used in mines that are dangerous because of gas or coal dust must be selected from this permitted list, which now includes more than fifty explosives.

Similar restrictions in the use of unsafe explosives were enforced in Great Britain in the coal-mines regulation act of 1887, and control of like kind is exercised in France, Belgium, and Germany. In all these countries the restriction of unsafe explosives has caused the development of "safety" explosives, which have proved greatly superior to those previously in use. The stimulating effect that the restriction of the more dangerous types of explosives has had on the invention and testing of safety explosives is well shown by the number of safety explosives devised each year. These explosives are as satisfactory in every respect as the common powder previously in use, and yet are free from most of the danger of causing mine explosions, inseparably connected with the use of the older explosives. Several of the newer explosives, for example, have been found to be incapable of igniting an explosive mixture of fire damp and air, even when the charge of the explosive is 700 grams; whereas as little as 30 grams of the older explosives would invariably cause an explosion of fire damp.

In Belgium, owing to the greater amount of fire damp present in the mines of that country, a further restriction, known as the charge limit, has also been put in force. Through this restriction the maximum amount of any explosive which is allowed to be used in any single charge is defined. The actual amount allowed varies according to the relative liability of the explosive to ignite fire damp, but with all the better class of explosives it is well above the amount needed for use in a single charge under proper mining conditions.

These restrictions in the kind and amount of explosives have yielded an additional benefit in the fact that the reduction in the amount used not only reduces the number of accidents, but also to a large degree prevents coal waste. The miner finds that with the restricted amount of explosive allowed it is necessary to mine by machine or hand in order that the explosive may produce the coal, and a larger per cent of lump coal is consequently produced. He also finds that the props for supporting the roof can be set closer to the face of the workings, the smaller amount of explosive being less liable to knock them down. The miner in this manner secures greater protection through the increased support of the roof.

The importance of this work in regard to the prevention of accidents from explosives has been well summarized by V. Watteyne, chief engineer of the administration of mines, Belgium, as follows:

> The use of explosives is, and especially was, the principal cause of danger of explosion in the mines. It is this cause which, previous to 1890, before the generalization of safety explosives and before the use of explosives of every description had been reduced by various means to a minimum, brought about deadly catastrophes. Within the decennial period 1880–1889 the number of victims of ignitions caused by the use of explosives reached 90 per cent of the total number of victims of explosions in mines.
>
> It may be asked, What is the reason for such a preponderance, considering that the number of lights introduced into the mine by the lighting apparatus is far greater than the number of shots? It would be too long to examine here in detail the causes of the greatest danger of explosives, but we will mention the principal ones in a few words. On one hand the safety lamp, though still imperfect, has acquired a fair degree of safety; on the other hand, the flame of a lamp, even when uncovered, can not ignite a fire-damp mixture unless its proportion of fire damp be very high, say 6½ to 7 per cent, a proportion which the aspect of the flame betrays in a very apparent manner a long time before; nor can it ignite a mixture of dust. The case is different with the violent flames caused by the explosion of charges, for these are not only liable, by the shock they produce in the atmosphere of the workings, to call forth to the dangerous point an unexpected rush of fire damp, but they can ignite the clouds of dust which this very commotion has raised, and in this way can bring about terrible catastrophes, while in consequence of the apparent absence of fire damp one may think himself nearly safe.
>
> The endeavors made after 1887, in consequence of disastrous explosions, to reduce the danger of explosives have brought about a very sensible reduction of the number of the victims of blasting. Thus within the following decennial period, from 1890 to 1899, in spite of the awful accident of Anderlues, which, in 1892, made 160 victims, the total number of men killed by mining explosions in Belgium has been reduced to 258, from the previous figure of 455, the proportions of victims of ignition by the use of explosives having fallen to 23 per cent.

In connection with the foregoing statement the following table will prove of interest, showing the remarkable increase in the use of safety powder in Belgium during ten years, coincident with the decrease in the use of black blasting powder for the same period.

Use of safety explosives and black blasting powder in the coal mines of Belgium.

Year.	Safety explosives.	Black powder.
	Kilograms.	*Kilograms.*
1895	80,786	689,344
1897	128,870	557,900
1899	176,440	465,648
1901	247,849	442,780
1903	399,821	415,292

It should be further noted that the black powder was restricted to mines not containing fire damp.

STORAGE OF EXPLOSIVES.

Regulations governing the storage of explosives for use in coal mines are in general effect in European coal-producing countries, and provide that no explosive substance shall be stored in the mine, that no explosive shall be taken into a mine except in canisters containing not more than 5 pounds, and that no unused powder shall be left in a mine over night. The amount of powder in the possession of a workman at any one time is also limited, and the amount which can be taken into a mine is usually restricted to that which will be used in one shift.

SHOT FIRERS.

Regulations enforced in Great Britain provide that in all mines in which inflammable gas is present or has been found in dangerous quantities within the previous three months all charges of explosives shall be fired by a competent person, termed a shot firer. The object is to place responsibility in the hands of men better qualified for the work than the average miner. The shot firer begins his work after the miners have left for the day, each miner before leaving having prepared a number of holes in such places as he wishes charges to be fired. The shot firer charges the holes with explosive and tamps and fires the charges.

It will be seen that by this method the charges are fired at a time when but few men are in the mine, and that accordingly, if a fire-damp explosion occurs, fewer lives are lost than if the miner fired the shots at a time when other miners were in the workings.

Still another factor of greater importance is that the shot firer, through constant experience, soon becomes used to the proper use of explosives, and also learns to charge the holes and fire them in the safest way possible. The shot firer is also free from the temptation to use excessive charges in the desire to get out a great amount of coal with the least possible effort. It is well known to all persons experienced in coal mining that overcharging of holes and mining by means of large shots fired in the solid mass of the coal bring about many fire-damp and coal-dust explosions.

At the present time several electrical shot-firing devices are being tested, with some promise of effecting a considerable saving of life. The main principle of these devices is the firing of the charges one after another at proper time intervals. As already stated, the firing of the charges takes place after the miners have left for the day, and the entire operation of the devices is automatic. It is of course necessary, after the charges are fired, to have some one examine each room in which a shot has been fired to see that conditions are normal, and that no feeders of gas have been ignited which might start a mine fire. The use of shot-firing devices or some other means equally safe is required by regulation in Great Britain.

MATERIALS USED FOR TAMPING.

The use of drill dust, slack coal, or other inflammable material for tamping is forbidden in European coal-producing countries, it having been found that gas and coal-dust explosions are more likely to occur when such materials are used. The laws of Great Britain compel the use of clay or like substance for tamping. The material is delivered to the miner near the working place.

WATERED ZONES.

The watering of the sides and roof of coal-mine passageways has been found to be of material benefit in preventing local ignitions of coal dust from becoming general. The watering prevents the coal dust from being stirred up by a small explosion, and the reduction in the explosive properties of the wet coal dust has the general effect of preventing an explosion from traveling into other workings. As dust explosions gain in destructive effect the farther they travel, it is believed that the thorough watering of zones greatly reduces the destructive effect of such explosions.

The watering is effected by means of sprinkling or spraying devices of various kinds. Specially constructed nozzles are in use, particularly in Germany, which produce a fine spray or mist by means of water under pressure, so that the air is thoroughly moistened.

An English commission has lately pointed out that sprinkling may produce a local weakening of the walls in some places, and the possibility of a slight increase in falls must accordingly be weighed against the advantages given by the protection from dust explosions.

AID TO THE INJURED.

The mining regulations of Germany, France, and Belgium require that mines shall be supplied with means for administering to the comfort of injured workmen and that proper appliances shall be provided for first aid.

Rescue devices equipped with small tanks of compressed air or compressed oxygen, or with some chemical appliance for generating a supply of oxygen, so as to enable a person to enter mine workings in which an irrespirable atmosphere is present, are required in some countries. By the aid of such apparatus rescue parties may enter the mine workings immediately after a fire-damp disaster and rescue injured miners, who would otherwise soon fall victims to the poisonous atmosphere surrounding them. Mine fires started by the ignition of feeders of fire damp may be brought under control much more easily when immediate efforts are made to combat them by men equipped with rescue devices.

ENFORCEMENT OF REGULATIONS.

In all European countries the enforcement of regulations in regard to coal-mine operations is placed in the hands of specially appointed officers or mine inspectors familiar with the industry and able to examine mining conditions intelligently and see that the mining laws are obeyed.

To insure compliance with the regulations, penalties are provided in case of noncompliance, and these penalties fall on the miner or the operator, or both, according to the nature of the violation. An injunction restraining the further operation of a mine until the laws have been obeyed is a further means in the hands of the mine inspector for insuring the enforcement of the law when the step is found necessary.

STUDY OF MINING CONDITIONS.

England, Germany, and Belgium maintain experiment stations where explosives are tested and where safety lamps, rescue appliances, and all other devices for use in mines may be examined. In France similar work is done by commissions which are appointed from time to time, and in other European countries there are permanent stations. It has already been pointed out in this paper that concurrently with the establishment of the experiment station, mine conditions begin to show the improvement that is so marked a feature of the statistics here presented. Safety lamps greatly superior to those previously in use were manufactured as soon as the defects of the earlier forms were pointed out at the experiment stations, and the development of improved forms of rescue appliances, electrical firing devices, and many other means of giving increased safety to mine workers have been inseparably connected with the stimulus given by these stations.

Inventors have been encouraged by the knowledge that the actual merits of any improvement they might make could be determined at the testing station, and at the same time mine owners have been able to see the results of thorough tests of all new devices, and to choose types of safety lamps, rescue appliances, and other devices, with a full knowledge of their working under actual mining conditions.

The experiments thus made have been of general benefit, and, aside from reducing the death rate from accidents in mines to a very low figure, they have been the means of bringing about improvements in operation that have been a substantial advantage to both mine workers and mine owners.

ACKNOWLEDGMENTS.

The statistics relating to mine accidents in the United States for the years 1905 and 1906 are taken from "The production of coal in 1906," by E. W. Parker, of the United States Geological Survey. The statistics relating to mine accidents in the United States for a number of years previous to 1905 are derived from tables prepared by F. L. Hoffman, expert mining statistician, and printed in the fifteenth annual report of the Tennessee mining department.

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The statistics of mine accidents in Belgium are taken from "Annales des mines de Belgique" or from "Les lampes de sureté et les explosifs," by V. Watteyne. The figures stated for France are from "Statistique de l'industrie minérale en France et en Algérie." The statistics for Prussia are from the "Zeitschrift für das Berg-, Hütten-, und Salinen-Wesen im preussischen Staate." The statistics for Great Britain were taken from "General reports and statistics, mines and quarries." The tables relating to accidents from falls of rock and coal are mainly from "Der Verhandlungen und Untersuchungen der Preussischen Stein- und Kohlenfall Commission;" and some general statistics of mine accidents were also obtained from that work.

The general excellence of the European reports is especially noteworthy, and the complete and careful classifications adopted by them have greatly assisted in the preparation of this report.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 333.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports, Q, Fuels; R, Structural materials. This paper is the seventh in Series Q, the complete list of which follows (PP=Professional Paper; B=Bulletin):

SERIES Q, FUELS.

B 261. Preliminary report of the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp.

PP 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. 3 parts. 1,492 pp., 13 pls.

B 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp.

B 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp.

B 325. A study of four hundred steaming tests made at the fuel-testing plant, St. Louis. Mo , in 1904, 1905, and 1906, by L. P. Breckenridge, 1907. 196 pp.

B 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to July 1. 1907, J. A. Holmes, in charge. 1908. — pp.

B 333. Coal-mine accidents: Their causes and prevention: a preliminary statistical report, by Clarence Hall and W. O. Snelling. 1907. 21 pp.

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